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Lo Parrino, Elia
Ficetola, Gentile Francesco
Manenti, Raoul
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Thirty years of invasion: the distribution of the invasive crayfish *Procambarus clarkii* in Italy

ELIA LO PARRINO^{1,*}, GENTILE FRANCESCO FICETOLA^{1,2}, RAOUL MANENTI¹,
MATTIA FALASCHI¹

¹ Department of Environmental Science and Policy, University of Milan, Via Celoria 26, 20133 Milan (Italy)

² Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, LECA, Laboratoire d'Écologie Alpine, F-38000 Grenoble (France)

* Corresponding author, email: loparrino.elia@yahoo.it

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SUMMARY

The presence of the red swamp crayfish *Procambarus clarkii* in Italy is documented since 1989, but no comprehensive data are available on its spread through time at the national scale. New confirmed records for *Procambarus clarkii* are continuously arising in recent years across the country. By reviewing the scientific and grey literature, we obtained an up-to-date map of the species invasion in Italy. This information can help to monitor and understand the spread of this highly invasive crayfish and to implement more effective management measures.

INTRODUCTION

Intentional and inadvertent introductions of alien species have become more frequent than ever in the last decades, due to the effects of globalization, particularly the increase of international trade (Westphal et al. 2008, Hulme 2009). Although the difficulty of understanding the effect of invasives may lead to the underestimation of their impacts (Williamson and Fitter 1996, Graves and Shapiro 2003, Ricciardi and Atkinson 2004, Rodriguez 2006), alien species are one of the greatest threats to global biodiversity (Gallardo et al. 2015, Doherty et al. 2016). An alien species can represent a threat to native species through various mechanisms, such as the

increase of predation rate (Gherardi et al. 2001, Wanless et al. 2007), competition for resources (Brown et al. 2002, Cadi and Joly 2003), spread of pathogens (Diéguez-Urbeondo and Söderhäll 1993), and food web alterations (Ficetola et al. 2012).

Biological invasions in freshwater habitats can cause degradation to various levels of biological organization, negatively affecting the entire ecosystem (Vilà and García-Berthou 2010, Gallardo et al. 2015). Inland waters are particularly susceptible to biological invasions and, in extreme cases, alien species can become a relevant part of freshwater communities, both in terms of the number of species and biomass (Strayer 2010). This vulnerability is due to

several factors, such as the high dispersal ability of some freshwater organisms along with the interconnected hydrographic network and the strong impacts of human disturbance on these environments (Gherardi et al. 2009). Furthermore, many freshwater species are specialists to environments with a limited set of predators and can be lacking adequate antipredator responses (Cox and Lima 2006). Accidental and deliberate introductions of alien freshwater animals or plants are usually linked to aquaculture, fishing activities, passive transport, and ornamental uses of exotic species (Vilà and García-Berthou 2010). The red swamp crayfish *Procambarus clarkii* Girard, 1852 is a crayfish native from the United States and northern Mexico and, due to its relevance for aquaculture, in the last decades, it was introduced in all the continents except for Antarctica and Oceania (Holdich 1993, Capinha et al. 2011, Loureiro et al. 2015). This crayfish has a generalist diet (Barbaresi and Gherardi 2000, Loureiro et al. 2015) and can tolerate extreme variations in oxygen level, water salinity and acidity, and even prolonged droughts (Claire and Wroiten 1978, Barbaresi and Gherardi 2000, Casellato and Masiero 2011, Loureiro et al. 2015). Its tolerance and its fecundity allowed this species to rapidly spread and successfully invade a large variety of habitats (Gherardi 2006, Aquiloni and Gherardi 2008, Siesa et al. 2014). Introduced red swamp crayfish populations are known to have a negative impact on several members of freshwater communities. For instance, *Procambarus clarkii* has a negative impact on the abundance and distribution of many amphibians (Cruz and Rebelo 2005, Cruz et al. 2008, Ficetola et al. 2011, Manenti et al. 2020), aquatic insects (Siesa et al. 2014), and on macrophytes biomass and biodiversity (Matsuzaki et al. 2009, Carreira et al. 2014). Moreover, *Procambarus clarkii* is a vector for the oomycete *Aphanomyces astaci*, causing the so-called crayfish plague, which is lethal for freshwater European crayfish species and already determined several local extinctions of native crayfish (Diéguez-Urbeondo and

Söderhäll 1993, Holdich 1993, Aquiloni et al. 2011, Loureiro et al. 2015, Bonelli et al. 2017, Manenti et al. 2019).

In Italy, the red swamp crayfish was observed for the first time in the wild in the Turin province in 1989 (Delmastro 1992), but it rapidly spread, originally in northern and central Italy and more recently also in the southern portion of the peninsula (Morpurgo et al. 2010, Aquiloni et al. 2011, Cilenti et al. 2017). However, so far no study has described the pattern and the rate of invasion by this species in Italy. The aim of this work is to provide updated information on the distribution of *Procambarus clarkii* in Italy using both scientific and grey literature such as management plans of protected natural areas, local fishing maps, biodiversity-dedicated websites, online forums, and local newspaper articles.

MATERIALS AND METHODS

The Italian territory is divided into 20 administrative regions, each one composed of a variable number of institutional bodies called “provinces” (Italian: “province”) or “metropolitan cities” (Italian: “città metropolitane”), hereinafter collectively referred to as “provinces” (total: 107 provinces). We focused on the distribution of *Procambarus clarkii* at the provincial level. We searched for distribution data of the red swamp crayfish through multiple search engines using the keywords “*Procambarus clarkii*”, “gambero rosso”, and “gambero killer” (the Italian common names for the red swamp crayfish) followed by the name of each Italian province. Since some provinces are no longer administratively valid, and some sources do not explicitly indicate the name of the province, we also performed searches using the name of each Italian region. The literature search was performed between December 2019 and February 2020. Searches for scientific literature were performed using Web of Science, Scopus, and Google Scholar, while searches for grey

literature (newspaper articles, fishing maps, and management plans) and online platforms (forums, and social networks) were performed using Google. Furthermore, we searched for *P. clarkii* records in the ClimCKmap database, a georeferenced database for the Italian fauna (Marta et al. 2019).

Collected data included: the occurrence of the species, the year and, when available, locality of first observation in the province, and the consulted source (Appendix S1). When the date of the first observation was not specified, *Procambarus clarkii* is considered present in the province since the date of publication of the oldest source assessing its presence. The locality of first observation, whether specified in the sources, is reported as the name of the municipality, natural protected area, stream, river, or lake where the red swamp crayfish was found. It must be stressed that the absence of occurrence data of the species in a province does not necessarily imply the absence of the species but only the lack of records.

We created a distribution map of *Procambarus clarkii* in Italy at the province resolution, with an indication of the first year of detection for each province (Figure 1, appendix S1). The distribution map was processed using QGIS 3.4.13 (<https://qgis.org/>) and the list and boundaries of the Italian provinces were retrieved from the Italian National Institute of Statistics (<https://www.istat.it/it/archivio/222527>, accessed on 18 February 2020).

RESULTS

We found records of *Procambarus clarkii* in 86 out of 107 Italian provinces (80.4%; Figure 1). The highest concentration of invaded provinces is in central Italy (Lazio, Marche, Tuscany, and Umbria regions), where the red swamp crayfish is present in all the provinces. In north-western Italy (Aosta Valley, Liguria, Lombardy, and Piedmont regions) it is present in 24 out of 25 provinces (96%) and in north-eastern Italy

(Emilia-Romagna, Friuli-Venezia Giulia, Trentino-Alto Adige/Südtirol, and Veneto regions) it is recorded in 20 out of 22 provinces (90.9%). In insular Italy (Sardinia and Sicily) fewer records are available and crayfish was detected in 9 out of 14 provinces (64.3%). Finally, in Southern Italy (Abruzzo, Apulia, Basilicata, Calabria, Campania, and Molise) the species was detected in 11 out of 24 provinces (45.8%). From 1989 to 1999 *Procambarus clarkii* was observed in 22 provinces; between 2000 and 2009 it invaded 38 new provinces (+172.7% compared to the previous decade); in the last decade (2010-2019) the red swamp crayfish has been recorded in 26 additional provinces (+43.3%) (Figure 2).

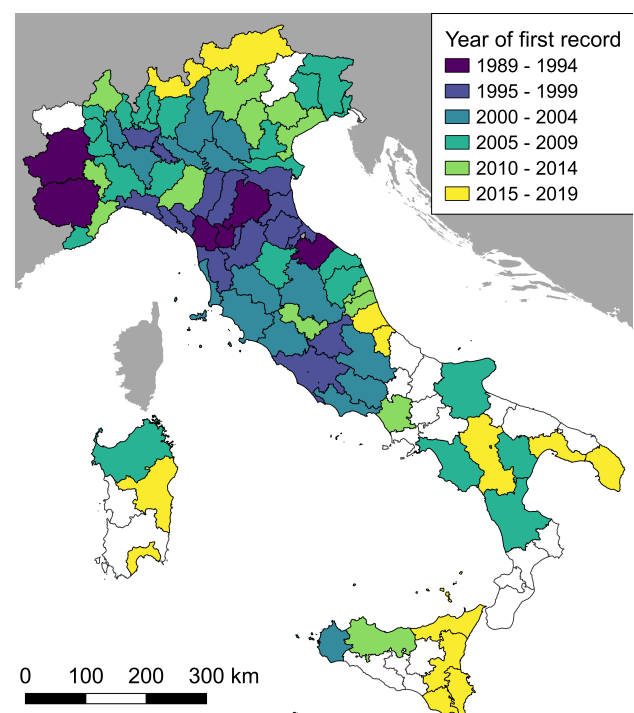


Figure 1. Distribution map of *Procambarus clarkii* at the provincial level. The colors represent the different periods of first observation of the species. Grey represent territories outside the Italian boundaries.

DISCUSSION

The range of *Procambarus clarkii* underwent an impressive expansion in Italy since its first introduction thirty years ago (Figure 1). This is

probably due to both natural dispersal and multiple deliberate or accidental introductions (Gherardi et al. 2001, Gherardi 2006). Given the major impacts of the crayfish on biodiversity, the high number of invaded provinces in northern and central Italy raises major concerns for the conservation of wetlands in these areas. Looking at the number of invaded provinces over time (Figure 2), it seems that the crayfish spread was fastest during the second decade after the introduction and then slowed down in recent years. However, this deceleration is due to the fact that the more the range of this invasive species expands, the fewer provinces remain not invaded and therefore colonizable (Figure 2).

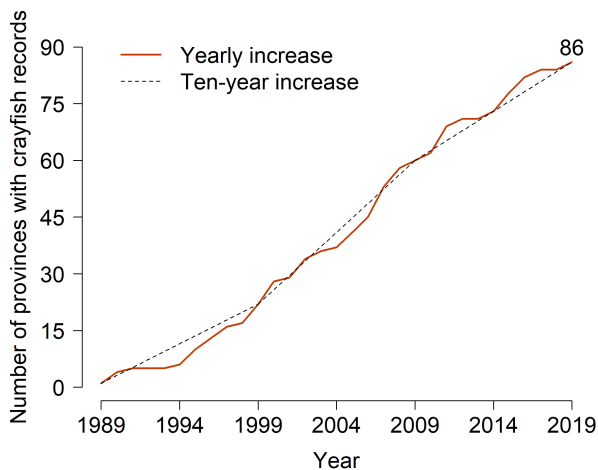


Figure 2. Cumulative number of invaded Italian provinces since the first observation of *Procambarus clarkii* in the wild.

We observed sharp differences between northern/central regions, where almost all provinces are invaded, and southern/insular regions, where fewer records are available (Figure 3). Several non-exclusive reasons can determine this spatial pattern. First, the difference could be caused by different habitat availability for the crayfish across the country, for instance, because northern and central regions have a larger extent of inland waters compared to the southern/insular regions (Allen and Pavelsky 2018). Second, introductions of

alien species are more frequent in areas with high human density (Stohlgren et al. 2006, Silva-Rocha et al. 2019), and human population is particularly dense in some of the northern/central regions. Third, differences could be caused by historical reasons. The oldest observations of *Procambarus clarkii* in Italy occurred in northern and central regions, while the first records in southern and insular Italy are more recent. Despite available data are not enough to unravel the reason behind the differences, this last explanation is supported by the rates of invaded provinces across the Italian territory: in north-western, north-eastern, and central Italy the rate of invaded provinces was fastest until 2009, followed by a plateau during the last decade. Conversely, southern and insular Italy showed no records until 1999, a slow increase in the second decade, and a fast increase in the last decade (Figure 3).

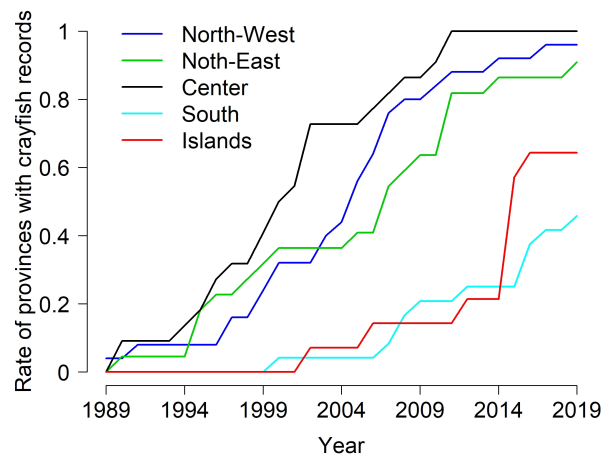


Figure 3. Proportion of provinces invaded by *Procambarus clarkii* in five areas of Italy. Regions included in each area: North-West = Aosta Valley, Liguria, Lombardy, Piedmont; North-East = Emilia-Romagna, Friuli-Venezia Giulia, Trentino-Alto Adige, Veneto; Center = Lazio, Marche, Tuscany, Umbria; South = Abruzzo, Apulia, Basilicata, Calabria, Campania, Molise; Islands = Sardinia, Sicily.

Therefore, in the last decade, the invasion rate in southern and insular regions seems to follow a pattern similar to the one previously occurred in northern and central

regions. Finally, we cannot exclude the role of sampling bias, given that for several taxonomic groups fewer distribution data are available from southern Italy (e.g. Sindaco et al. 2006).

To achieve a national-wide representation of the invasion, this study only reports the first records at the provincial level. However, more detailed data can help to improve our understanding of crayfish spread and impact. First, data at a finer spatial grain are needed to understand whether, in a given administrative area, the crayfish has invaded the whole territory or is limited to specific areas/habitats. Second, the impact of invasive species generally increases with their abundance (Leung et al. 2012). Standardized monitoring efforts, providing measures of abundance, would be extremely important to identify the areas where the crayfish impact can be highest. Finally, distribution data can be combined with information on environmental features and species dispersal to identify the drivers of the invasion and help to prevent the invasion of the environments that remain crayfish-free (Siesa et al. 2011, Hefley et al. 2017, Falaschi et al. 2018).

This update of *Procambarus clarkii* distribution in Italy underlines the importance of monitoring invasive species of concern, in order to fill distribution gaps and to map the species distribution in more detail. Given the strong negative impacts of this crayfish on native biodiversity, its current widespread distribution stresses the urgency of rapidly implementing efficient containment strategies to avoid further spread and limit the negative impacts (Falaschi et al. 2020). Predation upon the red swamp crayfish is known for some native species, such as the European eel *Anguilla anguilla* (Aquiloni et al. 2010), the European pond turtle *Emys orbicularis* (Ottonello et al. 2005), the European otter *Lutra lutra* (Prigioni et al. 2009), the red fox *Vulpes vulpes* (Correia 2001), and many birds (Correia 2001, Gherardi 2006, Delsinne et al. 2013). However, predation, particularly by birds, does not seem to negatively affect the persistence of

Procambarus clarkii populations (Correia 2001). Containment is probably the only way to preserve the remaining non-invaded territories since the eradication of the red swamp on a large scale is currently not feasible due to the huge amount of economic resources needed and to the lack of techniques able to effectively remove crayfish without impacting on native freshwater species (Peay 2001, Aquiloni and Gherardi 2010, Aquiloni et al. 2010, Cecchinelli et al. 2012).

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